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GRAVITY IN THE INTERIOR OF THE EARTH

By R. MELDRUM STEWART

ABSTRACT

General formulae are developed which show the manner in which the existence of maxima and minima of gravity in the interior of the earth is dependent on the variation of density with distance from the earth's centre.

Several special cases are discussed among which is the assumed approximation of a succession of layers, each of uniform density, separated by definite surfaces.

In an added note, an article by Benfield, listing values of density and gravity at various depths, is compared with the conclusions of this paper.

INTRODUCTION

IN our college days we learned that the central attractive force at any point within a sphere of uniform density is proportional to the distance from the centre, and consequently increases from the centre to the surface. What many of us have perhaps not paused to realize is that if the density is not uniform this law no longer holds, and that maxima and minima of the attractive force are possible. In the case of the earth, for example, we know from absolute determinations of the force of gravity that the average density is several times as great as that of surface rocks; we also know from seismological data that there are at least several layers of more or less constant density, separated by surfaces where the density changes with comparative suddenness, these changes being, so far as known, from a lower to a higher value as we pass inwards.

It is the purpose of this paper to investigate theoretically the conditions under which maximum and minimum values of gravity occur. In what follows it will be assumed that the earth is a perfect sphere, without rotation, and that the distribution of density is symmetrical about the centre. These conditions are probably sufficiently near the truth to give what is in essentials a true picture.

Development of Formulae

In general, $gr^2 = M = 4\pi\int_0^r \rho r^2 dr$ and by successive differentiation

$$r\frac{dg}{dr} + 2g = 4\pi\rho r \quad \ldots\ldots (1)$$

$$r\frac{d^2g}{dr^2} + 3\frac{dg}{dr} = 4\pi\frac{d}{dr}(\rho r) \quad \ldots\ldots (2)$$

$$r\frac{d^3g}{dr^3} + 4\frac{d^2g}{dr^2} = 4\pi\frac{d^2}{dr^2}(\rho r) \quad \ldots\ldots (3)$$

$$r\frac{d^4g}{dr^4} + 5\frac{d^3g}{dr^3} = 4\pi\frac{d^3}{dr^3}(\rho r) \quad \ldots\ldots (4)$$

etc.

We have also $g = \frac{4}{3}\pi\bar{\rho}r$, where $\bar{\rho}$ is the average density within the sphere of radius r. We note in passing that it follows from this relation that g in all cases passes through the same stages as $\bar{\rho}r$. Combining the above relation with equation (1) we obtain

$$\frac{dg}{dr} = 4\pi(\rho - \tfrac{2}{3}\bar{\rho}), \quad \ldots\ldots (5)$$

an equation which defines the critical values of g. It is clear from (5) that $\frac{dg}{dr}$ may be either positive or negative or zero, the zero value (critical value of g) occurring whenever $\rho = \frac{2}{3}\bar{\rho}$.

If $\frac{dg}{dr} = 0$, it follows from (1) that $g = 2\pi\rho r$. In that case, from (2), g is a maximum or minimum according as ρr is decreasing or increasing; if ρr is stationary $\frac{d^2g}{dr^2} = 0$, and we see from (3) that g

is stationary between increasing stages if ρr is a minimum, and stationary between decreasing stages if ρr is a maximum; similarly it follows from (4) that g is a maximum if ρr is stationary between decreasing stages, and a minimum in the converse case, and so on. Stated in another way, a maximum of g is possible only if ρr is decreasing, or stationary between decreasing stages, and a minimum only if ρr is increasing, or stationary between increasing stages.

It follows from (5) that the necessary and sufficient condition for a maximum of g is that $\rho - \frac{2}{3}\bar{\rho}$ shall pass from a positive to a a negative value as r increases, and conversely for a minimum. Thus, in any zone bounded by internal and external radii r_1 and r_2, with corresponding densities ρ_1 and ρ_2, (subject to the condition that $\rho - \frac{2}{3}\bar{\rho}$ does not pass through a zero value *twice* in the zone) g will pass through a maximum if, and only if,

$$\left.\begin{aligned} \rho_1 &> \tfrac{2}{3}\bar{\rho}_1 \\ \rho_2 &< \tfrac{2}{3}\bar{\rho}_2, \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

and similarly for a minimum.

But, by definition,

$$\begin{aligned} \bar{\rho}_2 &= \frac{3}{r_2^3}\int_0^{r_2} \rho r^2 dr \\ &= \frac{3}{r_2^3}\left[\bar{\rho}_1 \int_0^{r_1} r^2 dr + \bar{\rho}_0 \int_{r_1}^{r_2} r^2 dr\right]. \\ &= \bar{\rho}_1 \frac{r_1^3}{r_2^3} + \bar{\rho}_0\left(1 - \frac{r_1^3}{r_2^3}\right), \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7) \end{aligned}$$

where $\bar{\rho}_0$ is the average density of the zone.

Substituting in equations (6), and re-arranging, we obtain (subject to the condition above) as the necessary and sufficient conditions for a maximum or minimum respectively

$$\rho_1 \lesseqgtr \tfrac{2}{3}\bar{\rho}_1 \lesseqgtr \rho_2 \frac{r_2^3}{r_1^3} - \tfrac{2}{3}\bar{\rho}_0\left(\frac{r_2^3}{r_1^3} - 1\right) \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

In the general case these conditions can not be definitely evaluated without detailed and specific knowledge of the relationship between ρ and r throughout. However, several special cases are of interest.

Layer of constant density ρ.—In this case ρr increases throughout the layer and, as we have seen above, no maximum of g is possible.

Also, $\rho_2 = \bar{\rho}_0 = \rho_1 = \rho$, and, from (8), the conditions for a minimum become

$$\rho < \tfrac{2}{3}\,\bar{\rho}_1 < \tfrac{1}{3}\,\rho\left(\frac{r_2^3}{r_1^3} + 2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

In other words, the density must be sufficiently small in relation to that of preceding layers, and the layer must extend outward sufficiently far, so that $\frac{r_2^3}{r_1^3} > 2\left(\frac{\bar{\rho}_1}{\rho} - 1\right)$. Both conditions are obviously possible of fulfilment.

Surface separating densities ρ_1 and ρ_2.—We may consider the surface as an indefinitely thin layer, so that (8) still holds, and $r_1 = r_2$. If the change in density is a decrease, ρr decreases, and a minimum of g can not occur. From (8), the conditions for a maximum become

$$\rho_1 > \tfrac{2}{3}\,\bar{\rho} > \rho_2, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

conditions which obviously may be fulfilled. If the change of density is an increase (a condition which is not usually considered to be fulfilled anywhere in the earth's interior) a maximum of g can not occur, and the conditions for a minimum become

$$\rho_1 < \tfrac{2}{3}\,\bar{\rho} < \rho_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

The same results may be arrived at directly, by considering the values of $\frac{dg}{dr}$ just inside and just outside the boundary surface, as derived from (5).

Central Zone.—If, as is sometimes assumed, the density is constant throughout this zone, $\bar{\rho} = \rho$ at all points, and $\frac{dg}{dr} = \frac{4}{3}\pi\rho$, from (5), and g increases throughout; hence neither maximum nor minimum exists; there will be a maximum at the outer boundary if $\rho_2 < \frac{2}{3}\,\rho$, where ρ_2 is the density at the inner edge of the next layer. If the density decreases, ρr nevertheless increases for a certain distance at least, since $\rho r = 0$ at the centre. So long as ρr continues to increase no maximum of g is possible, as is seen from (2); also, since g is increasing near the centre, no minimum can occur until after the first maximum has been passed. If after a certain stage

the decrease in ρ becomes more rapid, so that ρr begins to decrease, a maximum is possible, and will occur if ρ becomes equal to $\frac{2}{3}\bar{\rho}$. This will be the case if the zone extends far enough, since

$$\bar{\rho} = \frac{3}{r^3}\int_0^r \rho r^2 dr$$

$$= \tfrac{3}{2}\rho - \frac{3}{2r^2}\int_0^r r^2 d(\rho r),$$

and since the integral finally passes from a positive to a negative value if r is sufficiently great.

Summary

According to a sometimes accepted picture the earth consists of successive zones separated by definite spherical surfaces, each zone being of constant density, with the densities of successive zones decreasing as we proceed outwards. This picture is perhaps over-simplified, but it will be of interest to set down the conditions for maxima and minima of g.

Designate the densities of the various zones by ρ_1, ρ_2, ρ_3, etc., these quantities being in decreasing order of magnitude; the nth zone, of density ρ_n, will have as boundaries r_{n-1} and r_n.

As we have seen above, g increases as we proceed outward through the central zone, and neither maximum nor minimum can occur (except that a zero value occurs at the centre); minima are possible in the various zones, and maxima at the separating surfaces. The conditions for a minimum in the general zone n are, from (9),

$$\rho_n < \tfrac{2}{3}\bar{\rho}_{n-1} < \tfrac{1}{3}\rho_n\left(\frac{r^3{}_n}{r^3{}_{n-1}} + 2\right), \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

and, from (10), those for a maximum between zones $n-1$ and n are

$$\rho_{n-1} > \tfrac{2}{3}\bar{\rho}_{n-1} > \rho_n. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

In each case the first inequality gives the condition that the minimum or maximum *may* occur (dependent on previous conditions), and the second the condition that it *will* occur if the first condition is fulfilled. Thus, for example, in (12) the initial condition is that ρ_n shall be small enough, and the second that r_n shall be great enough; and similarly for (13).

If the above assumed conditions do not hold throughout, so that, for example, the density in zone n is *greater* than that in zone $n-1$, it is obvious from (13), and, indeed, from the fundamental fact that ρr increases, that a maximum can not in this case occur at the separating surface; there may, however, be a minimum, the conditions for this being

$$\rho_{n-1} < \tfrac{2}{3}\,\bar{\rho}_{n-1} < \rho_n. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

The first condition means, as shown by an examination of (12), that r_{n-1} is not sufficiently great for a minimum to have occurred in zone $n-1$, while the second indicates that the density in zone n must be sufficiently great. If a minimum occurs, it is obvious from general considerations that the next maximum can not take place until we reach a separating surface where the density again diminishes. These conditions may be completely analyzed by use of equation (14).

In all the above cases it is clear that, if the depths and densities of the various zones are known, it is possible, by means of (12), 13), and (14), to evaluate exactly the positions of all maxima and minima, as well as the resultant values of gravity, since in general

$$\bar{\rho}_n = \frac{\rho_1 r_1^3 + \rho_2(r_2^3 - r_1^3) + \ldots\ldots + \rho_n(r^3{}_n - r^3{}_{n-1})}{r_n^3}.$$

Thus if we wish to investigate the minimum in zone n, we have $\rho_n = \frac{3}{2}\,\bar{\rho}_r$, from which we obtain immediately

$$r^3 = \frac{2}{\rho_n}\,[\rho_1 r_1^3 + \rho_2(r_2^3 - r_1^3) + \ldots\ldots +$$

$$\rho_{n-1}(r^3{}_{n-1} - r^3{}_{n-2}) - \rho_n r^3{}_{n-1}].$$

If this value of r falls between r_{n-1} and r_n, there is a minimum of g at distance r, with $g = 2\pi\rho_n r$; otherwise no minimum exists in that zone. Similarly, a maximum will exist at distance r_{n-1} if, and only if, the inequalities in (13) hold, in which case $g = \frac{4}{3}\,\pi r_{n-1}\bar{\rho}_{n-1}$. And so for the conditions envisaged in (14).

If, on the other hand, the structure does not consist of zones of constant density, we must fall back on inequalities (8) or their equivalent, which can not be definitely evaluated without knowledge of how ρ depends on r at every point.

Addendum

It has been drawn to the attention of the writer that Benfield[1] has listed values of ρ and of g for various distances from the earth's centre, and it was suggested that it would be of interest to check the positions of the maxima and minima of g against the conclusions arrived at in this paper.

To implement equation (7) it should be noted that, between radii r_1 and r_2, $\bar{\rho}_0$ is given by

$$\bar{\rho}_0 = \frac{3}{r_2^3 - r_1^3} \int_{r_1}^{r_2} \rho r^2 dr$$

It was assumed[2] that the density within the core ($r = 0$ to $r = 3470$) is given by

$$\rho = A - Br^2 - Cr^3;$$

this, on the basis of the figures given by Benfield, leads to the value 10.71 for the mean density of the core. It has been further assumed (again on the basis of Benfield's figures) that, between $r = 3470$ and $r = 5270$, the density varies uniformly. The results lead to the annexed table, in which the first two columns are taken from Benfield's article. The values of the table are further illustrated in figure 1.

It is obvious that no critical value of g exists within the core, since there is a minimum ($g = 0$) at the centre, and ρr increases throughout. As shown by the last column of the table, there is a maximum at 3470 (the outer boundary of the core), a minimum between 4470 and 4870, and a maximum between 5900 and 6200. These findings agree with those of Benfield, except for the fact that he places the final maximum at 5897. But it appears to be clear, on the basis of his own figures, that there could be no maximum between 5670 and 5900. For this would require $\bar{\rho}$ at 5670 to be less than 6.585 ($\rho - \frac{2}{3}\bar{\rho}$ $+ve$) and at 5900 greater than 6.345 ($\rho - \frac{2}{3}\bar{\rho}$ $-ve$), and from (7) these conditions would involve a mean density greater than 4.45 in the intervening layer, which in turn would require a very large maximum of density within that layer.

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[1] *Zeitschrift für Geophysik*, vol. XIII, p. 157 (1937).

[2] Bullen, *M. N. R. A. S., Geophys. Suppl.*, no. 3, p. 395 (1936).

However, in an article by Jeffreys[1] (quoted by Benfield), in which densities for the upper layers are given, there is found a discontinuity at 5897, with a drop in density from 4.23 to 3.69. Since the other values given for the upper layers coincide with the values interpolated from Jeffreys' table, it appears likely that the figure 4.23 given from 5900 is a slip in printing, and should have read 3.69. This would give the maximum at 5897 as indicated.

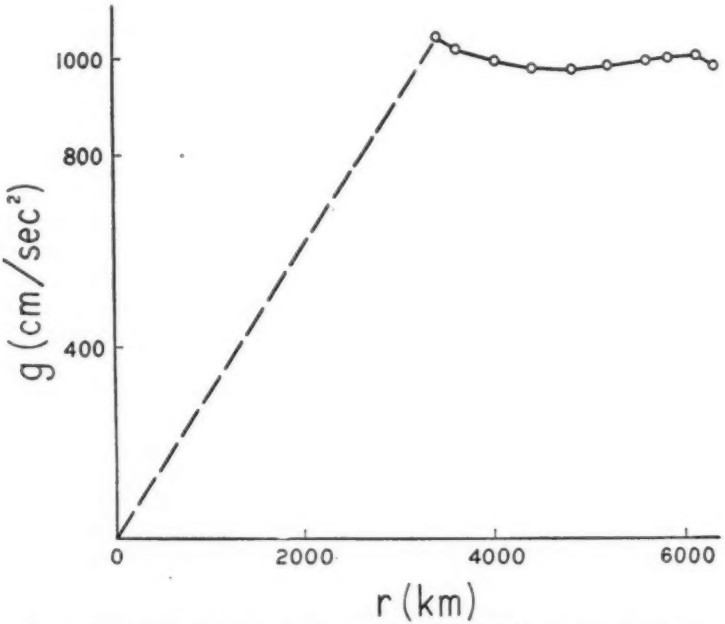

Fig. 1. Showing gravity as deduced from the values of $\bar{\rho}$ listed in column 4 of the table by substitution in the formula for gravity namely $g = \frac{4}{3}\pi G\bar{\rho}r$ where G is the gravitational constant and equals 66.7×10^{-9} C. G. S. and r is the distance from the centre of the earth in centimetres.

[1] *M. N. R. A. S., Geophys. Suppl.*, no. 4, p. 58 (1937).

TABLE I

Mean Densities and Values of $\rho - \frac{2}{3}\bar{\rho}$ *at Various Distances from the Earth's Centre*

r	ρ	$\bar{\rho}_0$	$\bar{\rho}$	$\rho - \frac{2}{3}\bar{\rho}$
		10.71		
3470	$\left\{\begin{matrix}9.75\\5.53\end{matrix}\right.$		10.71	$\left\{\begin{matrix}+2.61\\-1.61\end{matrix}\right.$
		5.48		
3670	5.43		9.90	−1.17
		5.33		
4070	5.23		8.68	− .56
		5.13		
4470	5.04		7.81	− .17
		4.93		
4870	4.84		7.16	+ .07
		4.74		
5270	4.64		6.65	+ .21
		<4.64		
		>4.39		
5670	4.39		<6.25	>+ .22
			>6.20	<+ .26
		<4.39		
		>4.23		
5900	4.23		<6.04	>+ .20
			>5.98	<+ .24
		<4.23		
		>3.44		
6200	3.44		<5.79	>− .42
			>5.63	<− .31
		<3.44		
		>2.67		
6370	2.67		<5.61	>−1.07
			>5.40	<− .93

AMERICAN ASTRONOMICAL SOCIETY: EIGHTY-FIRST MEETING

By C. A. CHANT

THE eighty-first meeting of the American Astronomical Society was held at the Dominion Observatory, Ottawa, Ont., on June 19-23, 1949. This was the third meeting of the Society at Ottawa, the two previous ones being in 1911 and 1929.

The members began to arrive on Sunday, June 19, many by automobile, and registered at the Dominion Observatory from 2.00 to 10.00 p.m. They were received by members of the local committee who were continually on duty giving information and assistance in securing suitable accommodation. A meeting of the Council of the Society was held at the Observatory at 3.00 p.m.; and during afternoon and evening there were informal tours of the gardens of the Dominion Experimental Farm which adjoins the Dominion Observatory grounds.

Next morning, Monday, June 20, the place of registration was at the fine building of the National Research Council, where all the sessions for papers were held. The total number registered was 133, and on adding wives and children the number of visitors becomes about 190. Also in attendance were members of the Dominion Observatory staff and of the Royal Astronomical Society of Canada. In all the total attendance was about 250. In the group photograph taken at noon on Monday there are 153 persons and at the Society dinner on Wednesday evening there were 157.

Of the contributed papers there are 54 titles printed on the programme. Two or three of these were not presented and four or five others were added later and listed on the blackboard. As usual, the subjects ranged over the entire universe, including planetary and double-star orbits, solar noises and radio waves, forbidden lines and proton reactions, and many others.

To no paper was assigned more than ten minutes and this limit was well observed. Nearly every paper was illustrated with lantern slides which seemed always to come on the screen at the proper moment. The writer has attended many meetings but at none has the organization and service been more efficient and smooth-

running. Abstracts of the papers will appear in the *Astronomical Journal.*

On Tuesday afternoon there was a Symposium on Meteoric Astronomy and in it there were delivered five notable addresses, as follows:

1. Some conclusions from over 3000 observations of meteors made with telescopes, by Charles P. Olivier, of the Flower Observatory.
2. One hundred meteor spectra, by Peter M. Millman, of the Dominion Observatory.
3. Determination of the size distribution of meteoric ionization columns, by L. A. Manning and Oswald G. Villard, Jr., of the Stanford Observatory.
4. Meteoric velocities determined by radio observations, by D. W. R. McKinley, of the Canadian National Research Council.
5. Comets, meteors, and the inter-planetary complex, by Fred L. Whipple, of Harvard College Observatory.

On Monday evening there was an At Home and Garden Party at the Dominion Observatory, and some 350 attended. To give to the visitors some notion of the nature and magnitude of the researches carried on by the Observatory a four-page leaflet had been prepared. The work is in Astronomy and Geophysics, and is organized into five divisions: positional astronomy, stellar physics, seismology, terrestrial magnetism, and gravity. Exhibits had been prepared indicating some of the activities of each division, and members of the staff were on hand to explain them and to answer any questions. The nineteen illustrations on the leaflet would help the visitor to remember what he had seen and heard.

On Tuesday evening the third Henry Norris Russell Lecture was delivered at the Victoria National Museum by S. Chandrasekhar, of the Yerkes Observatory, on "Turbulence—a physical theory of astrophysical interest." There was a good attendance and many lingered to examine the fine collection of meteorites of the Geological Survey and other exhibits in the Museum.

The Society Dinner at the Chateau Laurier Hotel on Wednesday evening was a very pleasant function. The toastmaster on this occasion was Fred L. Whipple, and he fulfilled his duties with efficiency and good nature. The chief speaker was H. L. Keenleyside, Deputy Minister of Mines and Resources, of which Department of the Federal Government the Dominion Observatory is a part. He was asked by the toastmaster to give some account of

his Department, and this was done with especial charm and felicity. Otto Struve, the president of the Society gave information on the work of the Society and its foreign relations, particularly in regard to the co-operation of Russia in the International Astronomical Union; and his report was not very hopeful.

The resolution of thanks was so well expressed that it is quoted in full here. For the opportunity to do so the writer is indebted to the kindly courtesy of the secretary, C. M. Huffer.

The American Astronomical Society wishes to express its appreciation to the Department of Mines and Resources of Canada for the fine support it has given and is giving to astronomical research. It is with particular pleasure that we have come to Ottawa for our eighty-first meeting. We have been impressed by the excellence of the facilities placed at our disposal for the formal sessions of our meeting, and equally pleased by the thoughtfulness with which our comfort and pleasure have been provided for.

We express our heartfelt thanks to the Department of Mines and Resources, to the Honourable Colin Gibson, Minister of the Department of Mines and Resources, to Dr. Keenleyside, the Deputy Minister, to Dr. Timm, Director of the Branch of Mines, Forests and Scientific Services, and to his successor Dr. Hume. We are equally appreciative of the kindness of the National Research Council of Canada in providing such excellent facilities in its fine building. We give our thanks to Dr. McKenzie, Director of the National Research Council, to Dr. Herzberg, Director of the Physics Division, and to the members of their staff who so well provided for our needs.

To Dr. and Mrs. C. S. Beals and the staff of the Dominion Observatory we express our special thanks for their kind invitation to meet here and for all they have done to make our stay here both pleasant and profitable. We thoroughly enjoyed the garden party and open house at the Dominion Observatory and offer our thanks to the observatory staff and to the Ottawa Centre of the Royal Astronomical Society of Canada for this pleasant occasion.

The ladies of the society are particularly appreciative of the tours to Mountain Lodge and to the Houses of Parliament especially arranged for their benefit. Many members of the Society who are able to spare an extra day are looking forward with pleasure to the tours planned for tomorrow.

For taking care of the many details which have added so much to the success of the meeting our special thanks go to Dr. and Mrs. Peter Millman and to those members of the Ottawa Centre of the Royal Astronomical Society of Canada who manned the registration desk.

At Mountain Lodge some of the ladies observed the following sign: "Why be Difficult when with just a little more effort you can be Impossible?" We know that we have been difficult guests at times, but we hope not too often impossible. If our generous hosts should be kind enough to say that we have not been *too* impossible, we can only say that it is their kindness and thoughtfulness which have kept us from expending that "little more effort."

At the conclusion of the dinner a very pleasing film was shown. It was entitled "Loon's Necklace" and illustrated some of the antics and methods of Indian medicine men. It was prepared locally and the many masks used in its production were from the collection in the Victoria Museum. On request it was repeated, and it was enjoyed by all.

At the Annual Business Meeting on Wednesday afternoon Alfred H. Joy, of the Mount Wilson Observatory, was elected the new President of the Society. It may be remarked that Andrew McKellar, of the Dominion Astrophysical Observatory, Victoria, B.C., was elected a member of the Council.

Some members stayed over in order to undertake field trips on Thursday morning to one or other of: the Bureau of Mines of the Department of Mines and Resources; the Division of Mechanical Engineering of the National Research Council, which serves as headquarters for aeronautical research in the Dominion; the Metcalfe Road Station of the Radio and Electrical Engineering Division of the National Research Council. The latter was the war-time centre for radar development and is now the site of intensive programmes concerned with the radio study of meteors, the sun and the galaxy.

RADIAL-VELOCITY CURVES FOR DELTA CEPHEI FROM LINES OF DIFFERENT CHROMOSPHERIC LEVELS*

By T. S. Jacobsen†

ABSTRACT

Radial velocities have been measured on ten three-prism spectrograms of *δ Cephei* using wave-lengths derived from plates of the sky and late-type stars. The lines are grouped into four different chromospheric levels and velocity residuals from the lowest level are plotted against phase. The plots establish a periodic variation for the hydrogen and high-level lines and indicate the existence of a similar effect in the intermediate level.

A series of ten uniformly exposed three-prism spectrograms of *δ Cephei*, giving a dispersion of 10.6 A./mm. at Hγ, was taken in 1936 by the author, using the 73-inch reflector of the Dominion Astrophysical Observatory, and measured by him four years later on the Gaertner measuring machine of the University of Washington. Two of the measures were repeated nine years later, closely reproducing in detail the previously obtained values. Further check plates, obtained in 1936 and measured concurrently with the *δ Cephei* plates, were as follows: eleven of *η Aquilae;* two of *γ Cygni*, F8p; one each of *α Persei*, F5, *ρ Cassiopeiae*, G5, *β Ceti*, K, *ζ Cygni*, K5; and nine of the sky. From the sky plates were derived the normal wave-lengths of the lines and blends as photographed and measured with the particular equipment used. The standard stars yielded corrections for spectral types to the normal wave-lengths obtained from the sky. The *η Aquilae* plates will be discussed in a later paper.

From the lists of Krieger,[1] Petrie,[2] and Hase[3] were selected forty-nine lines measurable on all the Cepheid and sky plates. Thirteen measurements of the nine sky plates were made the basis for the wave-length system. A definition of the position of the micrometer wire for a "bisection" of an unsymmetrical line, was

Contributions from the Dominion Astrophysical Observatory, No. 18.

†Associate Professor of Astronomy, University of Washington, Seattle.

[1]Krieger, J. C., *Ap. J.*, vol. 79, p. 98, 1934.

[2]Petrie, R. M., *Publ. Obs. Univ. of Michigan*, vol. 5, p. 9, 1932.

[3]Hase, V., *Pulkovo Bulletins*, vol. 11, p. 345, 1929.

formulated in terms of photographic blackening and rigorously adhered to in measuring. The selected lines and their grouping were as follows:

Group H:	Average height in sun's chromosphere 8000 km. λλ4101 (Hδ), 4340 (Hγ)
Group High:	Average height in sun's chromosphere 5500 km. λλ4078, 4216, 4227, 4247
Group Intermediate:	Average height in sun's chromosphere 1600 km. λλ4012, 4034, 4046, 4064, 4072, 4294, 4314, 4321, 4325, 4384, 4395, 4405, 4468, 4501
Group Low:	Average height in sun's chromosphere 700 km. λλ4028, 4033, 4036, 4041, 4062, 4084, 4100.7, 4103, 4107, 4158, 4175, 4177, 4200, 4219, 4222, 4227.5, 4236, 4250, 4251, 4254, 4319, 4326, 4376, 4418, 4427, 4459, 4467, 4476, 4482

The measurements were made with the highest available magnification, rendering the sharply focused individual silver grains easily visible. Settings were made on the whole lengths of the comparison and star lines. The reductions were made by the velocity standard method. The curvature correction was determined from a spectrogram of the sky, taken with a long slit. The values of the curvature reduced to settings made on the tips of the comparison lines are in close agreement with those used at Victoria. The corrections, in screw revolutions, were applied with opposite signs to the readings for star lines in a standard table computed from the finally adopted wave-lengths. In this way individual star lines were freed from the effects of curvature.

In spite of the considerable dispersion used, many of the lines were blends of two or more components. The average degree of blending in the nine excellent sky plates, ranging very slightly in photographic density on either side of normal, was taken as standard. Wave-lengths of these lines were derived from thirteen measurements of these plates. Corrections for plate velocities were applied to the individual wave-lengths before averaging. Thus the screw readings in the standard table are adjusted to give zero velocity with a normal sky plate taken at local apparent noon when the earth is on the line of apsides of its orbit.

The phases were computed from the heliocentric time of light

maximum in λ5700 (max.$_g$) by Stebbins' elements.[4] The middle of the series was 1936.677, or J. D. 2428415.38.

The spectral types were obtained from a curve constructed as follows. A smooth curve was passed through a plot of Shapley's observed values[5] of spectral type and phase. The shape and amplitude of this curve were left unchanged, but the ordinates were adjusted to F4 at maximum and G6 at minimum, so as to conform to the values in the general spectrum.[6]

The effect of spectral-type differences on the velocity differences of the various groups of lines was studied in the five comparison stars covering the spectral range encountered in the Cepheids. The differences found on the comparison star plates were plotted with spectral type, and values were read off from a smooth curve drawn through the plotted points. Corrections for spectral types were derived and applied to the Cepheid measures. No correction exceeds 2 km./sec., numerically. Because of the very discrepant values of the Hδ velocities on the comparison plates, only the Hγ-Low corrections were used with the H-Low group. A group Hγ-Low was also formed.

The final results appear in Table I, in which the heliocentric phases are reckoned in mean solar days from the nearest preceding light maximum in λ5700.[4] Regarded as a binary system, the periastron passage occurs $0^d.539$ earlier, as found from the author's 1923 elements[7] and Hertzsprung's slightly shortening period.[8] The velocities are in km./sec.

Plots of the above values show for all groups some relation to phase running through a cycle in one period. Due to some easily explained instrumental effect, the points of weight below unity stand above those of full weight; but except for a constant error, the low weight points follow the shape of the curve drawn through the points of full weight. The lower weights are assigned to plates affected by an asymmetry of all the lines, but most noticeable on the strongest lines. The comparison lines are shaded towards the

[4]Stebbins, J., *Ap. J.*, vol. 101, p. 47, 1945.
[5]Shapley, H., *Ap. J.*, vol. 44, p. 291, 1916.
[6]Payne-Gaposchkin, *Variable Stars*, p. 179, 1938.
[7]Jacobsen, T. S., *Lick Obs. Bull.*, vol. 12, p. 146, 1926.
[8]Hertzsprung, E., *Astr. Nach.*, vol. 210, p. 21, 1919.

violet and the strong star lines toward the red. The measuring process results in an apparent positive displacement of the stellar lines which is, however, completely compensated for on the average plate since the wave-lengths used were derived by measuring the same spectral features in similarly shaded sky material and adjusted to give the sky velocity of each plate. But an extreme case of

TABLE I

VELOCITY DIFFERENCES FOR DELTA CEPHEI

Helioc. phase*	Wt.	Sp.	Hγ-Low	H-Low	High-Low	Int-Low
.202	1	F4	− 2.8	− 1.7	− 2.1	− 2.0
.290	1	F4	− 5.6	− 4.4	− 1.9	− 1.1
.789	1	F4	− 5.2	− 2.3	− 1.2	+ 0.4
1.546	½	F8	+ 3.4	− 0.9	+ 2.1	+ 1.0
1.631	¼	F9	+ 2.7	+ 1.5	+ 1.1	− 1.8
3.611	1	G6	+ 0.9	+ 1.7	+ 5.0	− 0.6
4.285	1	G4	+ 4.0	+ 2.7	+ 2.6	0.0
4.481	½	G2	+ 6.7	+ 3.0	+ 3.6	− 0.4
4.625	1	G2	+ 2.1	+ 1.4	+ 4.5	+ 1.2
4.768	1	F6	− 0.1	+ 0.6	0.0	+ 0.7

*from maximum$_g$.

[9]Jacobsen, T. S., *Lick Obs. Bull.*, vol. 12, p. 146, 1926.

[10]Petrie, R. M., *Publ. Obs. Univ. of Michigan*, vol. 5, p. 27, 1932.

shading produces a positive displacement of the strong, with respect to the faint, absorption lines and thus *velocity differences* arise from this cause alone. Plots of Table I show that the three plates of inferior weight define curves of shape in general similar to those defined by the full weight plates, but more positive by the following constant amounts: for Hγ-Low, 6 km./sec.; for Hydrogen-Low, 2 km./sec.; for High-Low, 1 km./sec.; for Intermediate-Low, no appreciable constant error is indicated.

In figure 1 the points of inferior weight have been plotted with the corrections: − 6.0, − 2.0, − 1.0 km./sec., applied, respectively, to each of the three low weight observations in each of the three groups affected. Not enough comparison material of low quality

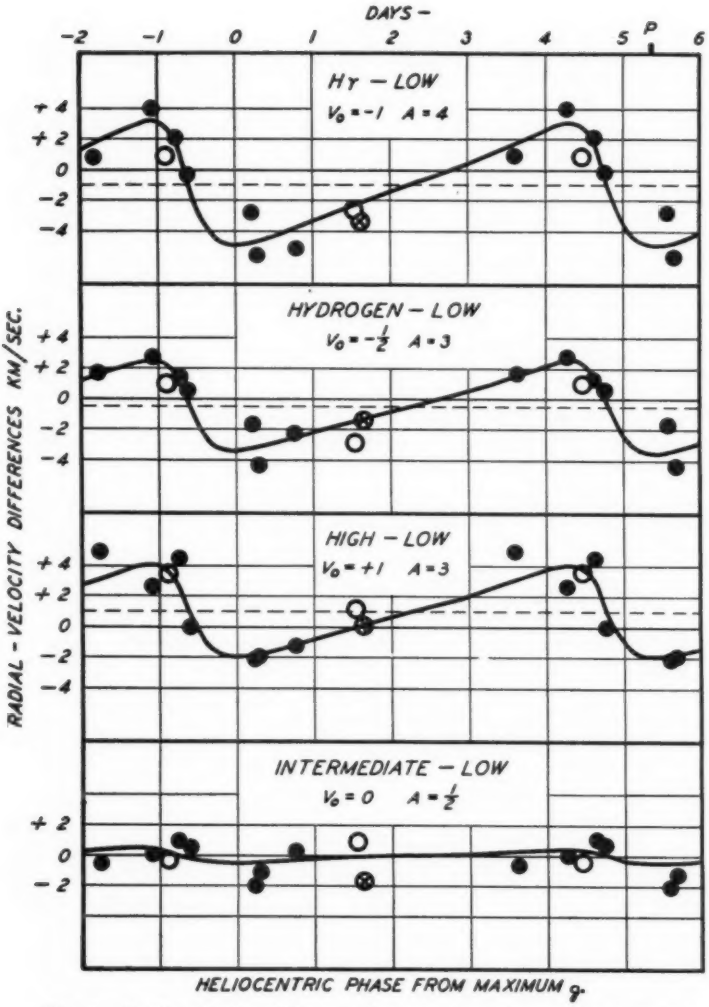

FIG 1. Radial-velocity differences between four chromospheric levels in Delta Cephei. Filled circles are of unit weight, open and crossed circles of one-half and one-quarter weights respectively. The latter two were lowered by arbitrary amounts, constant for each level.

exists to determine these systematic shadings independently, but if it is decided to lower the values obtained from the three observations of inferior weight by the above arbitrary amounts, these also add weight to the evidence for a relationship with phase in the velocity differences.

The velocity-difference curves were first drawn freehand and the approximate amplitudes, A, determined by inspection to be 4, 3, 3, and ½ km./sec., respectively. Using the elliptic elements of the author's total radial-velocity curve of 1923,[9] which was shown by a plot to be practically identical with that of 1936, three curves were computed using in place of the amplitude, $K = 19.75$, the values $A = 4$, 3, and ½. Keeping the phase of the point of maximum negative velocity coincident with that of the green light maximum, these curves were plotted and superposed upon the observations, varying slightly the position of the V_0 axis until the best fit was obtained. With values of V_0 equal to -1, $-\frac{1}{2}$, $+1$, and 0, for the groups Hγ-Low, H-Low, High-Low, and Int-Low, the computed curves of amplitudes 4, 3, 3, and ½, respectively, produced in each case a fit as close as could be desired. Thus a shape defined by a total velocity curve becomes a satisfactory velocity-difference curve after reduction of the amplitude by a constant factor. In this connection it is of interest to refer to an analysis by Petrie[10] of the mathematical shape to be expected in a velocity-difference curve in a star, in his case RT Aurigae, whose radial-velocity curve closely resembles the result of orbital motion in an ellipse. Petrie found, among the possible curves, one of the same form as that of the radial-velocity curve, reduced in amplitude by a factor, δ, (which may be either positive or negative), either preceding, agreeing, or lagging in phase with respect to the radial-velocity curve. Neglecting the above non-zero values of V_0, which are shown by the groups consisting of six or fewer lines, we can make a preliminary determination of the factor $\delta = A/K$, as having the values .20253, .15190, .15190, and .02532, respectively, for the four curves in Figure 1. The two Hydrogen-Low curves are considered to refer to the same height in the chromosphere, their differences being due to the discrepant values for Hδ. The Hγ-Low curve is therefore considered to be the more representative of the hydrogen level. The amplitudes of the first, third, and last curves,

4, 3, and ½, are nearly proportional to the corresponding differences in the atmospheric levels to which they refer, 7300, 4800, and 900 km. Thus the increase in the amplitudes of the velocity-difference curves with height above the lowest level considered is about 1 km./sec. per 1800 km. It is hoped that it will be possible to pursue this subject in the future from material large enough to warrant a least-squares adjustment to find the more exact values of the amplitudes as well as any slight phase lag which might here easily have escaped detection.

The conclusions from the present work may be summarized as follows:

1. From a discussion of ten high-dispersion spectrograms of δ Cephei a level effect was established.

2. The velocity-difference curves between the various chromospheric levels considered all have the exact shape of the total radial-velocity curve reduced in amplitude by a factor constant for any one level difference.

3. The amplitude of the velocity-difference curve increases with height above the 700 km. level at the rate of 1 km./sec. per 1800 km.

In conclusion the writer wishes to thank Dr. J. A. Pearce, Dominion Astrophysicist, for the opportunity to carry to a conclusion the discussion of this work begun so long ago, and Dr. R. M. Petrie, for many helpful discussions on systematic errors, wavelengths, and curvature corrections. He also wishes to recall the kindness of the late Dr. W. E. Harper, former Director of the Dominion Astrophysical Observatory who, in 1936, placed all the facilities of the institution at the writer's disposal.

University of Washington,
Seattle, Washington,
January 31, 1949.

COMMUNICATIONS
FROM THE
DAVID DUNLAP OBSERVATORY
Number 22

THE FIREBALL OF APRIL 3, 1949

By John F. Heard

ON the evening of Sunday, April 3, 1949, a very bright meteor, or fireball, was seen from many points in Ontario. Early reports by radio and press indicated that this was an unusually bright object, and that any meteorite resulting from it might have fallen in the neighbourhood of the Bruce Peninsula. On April 4, by radio and through the newspapers, information concerning the fireball was requested from those who saw it, by the writer in Toronto, by Dr. H. R. Kingston and Mr. W. G. Colgrove of the London Centre of the R.A.S.C., and by Mr. H. W. Seekins of the Guelph Centre. Approximately 77 reports were received as a result of these appeals. Dr. Kingston and Mr. Colgrove kindly turned over their reports to the writer, and Mr. Seekins, who himself had made an excellent observation, interviewed four other observers in the Guelph district and sent the reports to the writer. Mr. Don Fairbairn, through his CBL Neighbourly News programme, obtained a good many reports which proved particularly helpful. The writer wishes to express his appreciation to all of these gentlemen for their interested co-operation.

The following study is based largely on the results of 27 on-the-spot interviews with persons who saw the phenomenon—the four made by Mr. Seekins, and 23 made within a few weeks after the event by the writer in Toronto, Barrie, and Owen Sound districts. In addition, there were seven reports of particular value by persons who apparently took some pains, themselves, to measure the directions in which they saw the fireball. Twenty of these observations were used in determining the path of the fireball and

the remainder related only to the sounds heard after the appearance of the phenomenon. The remainder of the total of 96 reports were used for confirmatory purposes.

All the observers who reported by one means or another are listed in Table 1. The writer wishes to thank all these people.

TABLE I

OBSERVERS REPORTING THE FIREBALL

Toronto and district: Mrs. John Mills*, O. B. Thibaudeau*, Mrs. W. Constable, Mrs. R. Burgess, T. G. Rogers, George Murphy, R. J. Fairfull, G. E. Matthews, Dr. Louise Plumb, Elizabeth Roach, Toronto; A. J. Tilton*, Willowdale; H. F. Boake, Downsview; Mrs. H. E. Roland, Brampton; W. J. Cooper, Cooksville; N. S. Fleming, Whitby; Mrs. Hugh Carson, Oakville; Mrs. H. Matthews, Hamilton; Mrs. J. Meldram*, Mrs. D. Rodgers*, Aurora; Doris Dewsbury, Vandorf.

Guelph district: H. W. Seekins†, George Wood**, Hespeler; V. C. Lowell**, James Manton, Guelph; Mr. and Mrs. Stonehouse**, Miss M. Hummel, K. W. Farrow, Preston; Miss Francis Braucht**, Galt; Mrs. Levine, Hanover; E. M. Davidson†, Elora.

Barrie district: M. F. Frawley*, Mr. King*, Hillsdale, F. R. Miller, Ceylon; Mrs. W. Coburn, Beeton; Miss M. B. St. John, Sunderland.

Muskoka district: A. B. Penney†, Port Carling; M. Slater, Bracebridge; Mrs. Claude Bosley, Ardbeg.

Bruce Peninsula and neighbouring districts: Jack Youngs*, Ivan Butchard*, T. G. Fyfe*, Mrs. C. B. Smith, Lion's Head, Mr. and Mrs. Wes. Cox*, Norman Cox*, George Cole and sons*, Parkhead; Mrs. Adis*, Hugh Thomas*, Red Bay; John Hillditch*, Wiarton; J. Short*, W. Rayner*, Southampton; Gordon Brooke*, Port Elgin; H. Burke, Owen Sound; John Pettigrew*, Victor Miller*, Sauble Beach; Ivan Smith, Meaford.

Northern Ontario: E. H. Vaillancourt, Mrs. Allan Chalmers, Sudbury; A. G. Bridger†, Kirkland Lake; Miss Thelma Menzies, North Bay; Mrs. W. Rounding, Monetville; A. W. Ross, Coppercliff; Mrs. D. Selwood, Powasson.

Goderich district: Gavin Green*, Goderich; Mrs. A. E. Grange, Auburn; Mrs. W. Willits, Wingham; Mrs. L. Reynolds, J. Calder, Brussels; M. Elliot, Zurich; John Gaunt, Whitechurch; J. F. Slade, Kincardine.

Sarnia and Chatham districts: Mrs. Neil Wilkinson, Camlachie; J. F. Eckert†, Ridgetown; F. P. Graham†, Forest; Mrs. M. Watson, Thedford; Fred Watson, Watford.

London district: Jack Mackay, G. Dawson, Thamesford; John Peck, Kippen; Mrs. L. Reynolds, Exeter.

Woodstock district: Mrs. John Amos*, Woodstock; J. C. Bouckhuyte, Simcoe; Mrs. W. C. Larmon, Burgessville; Miss Annie Broughton, Paris.

Michigan: Miss Eleanor D. White†, Cedarville; Mrs. Abbott Gibney, Byron.

Eastern Ontario: Miss Anita Hyde, Trenton; E. P. Laberge, Ottawa; Mrs. Allan Northey, Lakefield; James Roberts, Peterborough.
Quebec: B. R. Ralfe, Gould.

* Interviewed by the writer.
** Interviewed by Mr. Seekins.
† Accurate bearings reported by letter.

Appearance and Brightness

The fireball seems to have appeared almost instantaneously with nearly its maximum brightness. Relatively few of the observers are sure that they saw it from the beginning, but those who did so describe it as "suddenly appearing", rather than as appearing first as an ordinary shooting star. The speed was distinctly slow. Nearly all observers who estimated the time of the flight placed it between 3 and 5 seconds.

The words which were most commonly used to describe the colour were greenish blue, greenish white, bluish white at the beginning of the path, and orange at the end of the path.

There was apparently a short tail perhaps about one degree long; some described it as sparks shooting out behind. No one at all spoke of bursts, in fact the impression conveyed is that it was remarkably uniform in general appearance and brightness throughout its path.

Only one observer described a persistent train. This observer was one of the closest to the actual path. He described the train as faint and lasting for fifteen seconds.

As regards brightness, a few described the landscape as being lit up as though by full moonlight, others as if by bright lightning. There was apparently good visibility outdoors and within unlighted rooms for a few seconds. Mr. Seekins, an experienced and careful observer, noted that at Hespeler the light of the fireball on the ground overpowered that of a street light one hundred feet away. From these reports the writer is inclined to set the stellar magnitude at about -10.

Sounds following the meteor by a minute or so were reported from the points of observation closest to the actual path. In some places these were of terrifying intensity. The sounds will be discussed in a later section.

Time of Occurrence

Most observations placed the time as shortly after 8.30 p.m. E.S.T. Mr. Seekins was the only one who read his watch immediately and checked it afterwards. He gave the time as 8.37. Two observers (who were together) gave the time as "positively after 9 p.m." but, for want of corroborative evidence, the idea of a second fireball at that time is discarded.

Range of Observations

Anticipating the results of a later section, the fireball was seen at heights between 80 and 30 miles over Lake Huron near the Bruce Peninsula shore. Observations were received from as far east as Gould, Quebec, a distance of 500 miles, from as far north as Kirkland Lake (250 miles), and from as far west as Cedarville, Michigan (near Sault Ste. Marie, 175 miles away) and Byron, Michigan (near Lansing, 225 miles away). No observations were received from south of Lake Ontario or Lake Erie. If the maximum height of 80 miles is correct the meteor would have been above the horizon for observers at distances as great as 700 miles. The Meteorological Service reports that on the evening of April 3 skies were mainly clear over Ontario and immediately to the south of the Great Lakes but largely cloudy east of Montreal.

The Observations

The observers were asked to point out or estimate the azimuths and altitudes of the beginning and end points of the illuminated path if they saw these, otherwise the first and last points which they did see. In all, 20 estimates of some or all four of these quantities were obtained. Two of the observers were able to relate these points to the stars, three others used a compass to obtain the azimuths and estimate the altitudes in degrees, and the fifteen others were asked, in on-the-spot interviews, to indicate the points while the interviewer made measurements. The results are listed in Table II.

The observations have to be treated with a good deal of caution. As it will appear later, this particular fireball was travelling at a small angle to the vertical, so that most observers saw the path almost at right angles to the horizon. Therefore their estimates and memories of the azimuth for the most part may be regarded as

TABLE II

OBSERVATIONS

No.	Lat. N.	Long. W.	First Appearance		Last Appearance		Remarks
			Az.	Alt.	Az.	Alt.	
1	43°43.2	79°22.4	292°	30°	298°	0°	
2	43 42.9	79 25.0	306	19	317	7	End points not seen
3	43 46.1	79 24.0	309	31	315	0	
4	44 01.0	79 29.7	279	14	281	0	Beginning not seen
5	44 36.6	79 42.0	256	13	286	1	
6	44 36.6	79 42.0	260	44	260	0	
7	44 36.3	79 42.5	277	40	277	0	
8	43 25.4	80 19.1	324	28	328	13	Beginning not seen
9	43 33.2	80 15.1	333	58	332	24	
10	43 21.6	80 19.1	315	50	310	25	End not seen
11	43 41	80 25	315	30	315	0	
12	45 05	79 29	240	45	240	0	
13	48 07	80 00	180	6	179	1	
14	43 04	82 00	000	..	000	6	
15	42 34	82 01	002	45	004	0	
16	46 00	84 23	130	28	130	0 ?	
17	44 59.2	81 15.3	198	40	235	15	
18	44 44.5	81 08.6	195	42	263	18	
19	44 26.5	81 23.0	052	34	021	3 ?	
20	44 33.9	81 03.7	..	90 ?	308	5	

Note: Azimuth is measured from the north clockwise

subject to accidental errors only. The altitudes, however, are undoubtedly subject to systematic errors. For example, whereas one experienced astronomer saw the end-point near a certain star in Cassiopeia at an altitude of 13°, others in the same locality believed it lasted right to the horizon. This is an example of the often-noted tendency to stretch out the illuminated path beyond its real limits. On the other hand, for observers close under the illuminated path, the beginning-point must have been nearly overhead; only one observer saw the beginning at an altitude greater than 60°; perhaps the others in this locality who believed thay saw

the beginning of the path actually only saw the fireball when it came into their range of vision as they scanned the horizon looking for the source of unexpected light on the ground.

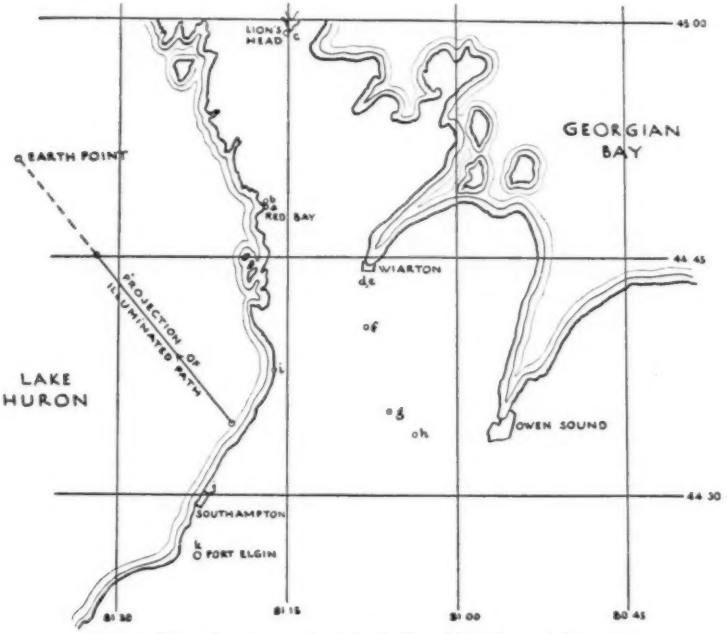

Fig. 1. Map showing path of fireball and location of observers.

The Projection of the Illumination Path

The positions on the earth's surface directly beneath the beginning and end of the illuminated path were found by plotting on a chart the positions of the various points of observation and, out of each of these points, drawing lines to represent the observed azimuths. Theoretically all these lines should meet in two points; actually, because of the errors of observation, they meet in two regions. Distant points of observation give rise to large uncertainties, of course, but closer points like nos. 17, 18, 19 and 20 in Table I remove much of the uncertainty.

The results finally arrived at for the positions of the projected points are: beginning, Lat. 44°34′.5 N., Long. 81°20′.0 W.; end, Lat. 44°45′.0 N., Long. 81°32′.0 W. These points are just off shore over Lake Huron as shown in figure 1. The distance between these points, the projected path-length, is 16 miles.

The Linear Heights

The heights of the beginning and the end points of the illuminated path may be calculated from the relation,[1]

$$H = d \tan h + d^2/2R,$$

where H is the linear height in miles, d is the distance in miles from the point of observation to the projection of the point on the path, h is the observed altitude in degrees of the point on the path; and R is the radius of the earth in miles. The term $d^2/2R$ arises from the earth's curvature and is very small for small distances.

For the height of the beginning-point, ten observations only were used. For seven of the twenty listed in Table II the beginning was definitely not observed; the "close-under" observations gave unreasonably low values for the height, so they were discarded as being probably unreliable for reasons stated earlier. The ten values of height ranged from 35 miles to 138 miles, the average being 79 miles with a probable error of ±6 miles.

For the height of the end-point only three observations were used. Few observed this point as anything but "on the horizon"; the close-under observations again gave unreasonably low values, and it was believed that they were subject to the "stretching-out" effect mentioned earlier. The three observations used gave values 26, 47 and 15 miles. The first of these was that of Mr. Seekins who observed the end-point with reference to the stars. Giving this observation double weight, the mean is 29 miles with a probable error of ± 4 miles.

The Earth-Point

It is usually of interest to calculate the position on the earth where the illuminated path, extended, would meet the earth's surface. Normally this would be the point near which one would expect to find any meteorites resulting from the phenomenon.

When we have the length of the projected illuminated path (16 miles) and the difference in height of the beginning and end points

(50 miles) we can calculate the slope of the path by simple trigonometry; it comes to 72°. Then we can easily calculate the distance of the earth-point beyond the end of the projected illuminated path, ignoring the earth's curvature in this instance because of the steepness of the path; it comes to 9 miles. This places the earth-point at Lat. 44°51.0 N., 81°39.0 W., about 13 miles off shore west of Red Bay. Needless to say no search for meterorites is proposed.

The Geocentric Velocity

The velocity with reference to the earth may be calculated if we know the real length of the illuminated path and the duration of visibility. The former is easily calculated by geometry from the quantities already known; it comes to 52 miles.

The duration of visibility was one of the quantities which observers were asked to estimate. Since most people have little experience in estimating short time-intervals, the following method was adopted: the observer was asked to reconstruct the scene in his mind, following the imagined path of the fireball with his eyes, and calling "now" and "now" for start and finish, while the interviewer took the interval with a stop watch. The results were surprisingly consistent both for separate trials with the same observer and from one observer to another. From six observers the estimated durations ranged from $3\frac{1}{2}$ to 5 seconds. The mean was taken as 4 seconds.

Thus the measured velocity with reference to the earth is 13 miles per second. This is called the apparent geocentric velocity, since the earth's gravitational pull has contributed to it. The true geocentric velocity u, that is, the velocity with reference to the earth before the body was affected by the earth's attraction, is related to the apparent geocentric velocity w, by the relation,[2]

$$u^2 = w^2 - 2gR,$$

where g is the acceleration due to gravity, and R is the earth's radius. This gives 11 miles per second for the true geocentric velocity.

The Zenith Attraction

The earth's attraction not only affects the speed of the body, it also alters the direction of its entry into the atmosphere unless it is entering at right angles to the earth's surface. Clearly, this effect

will tend to make the meteor's observed path more nearly towards the zenith; the effect is therefore called the zenith attraction. The zenith attraction ϕ, is given by the relation[2],

$$\tan \tfrac{1}{2}\,\phi = \frac{w - u}{w + u} \tan \tfrac{1}{2}\, z,$$

where z is the observed zenith distance, i.e., 90°−slope of observed path. In this case the zenith attraction comes to 1½° and thus the true zenith distance is 19½°.

The Radiant

The radiant, or direction in space from which the body was coming, may be calculated by spherical trogonometry, since we know the true zenith distance, the azimuth of the path (as measured on the chart, 142° clockwise from the north) and the time of occurrence. The result is:

Right Ascension 163°, Declination +28½°.

The Heliocentric Velocity

The geocentric velocity, even after being corrected for zenith attraction, represents only the combination of the earth's motion in its orbit and the meteor's motion in its orbit. This being an evening fireball, it can be anticipated that it was overtaking the earth. To calculate the heliocentric velocity m, of the fireball, that is, its velocity relative to the sun, we use the relation[1],

$$m^2 = E^2 + u^2 - 2uE \cos e,$$

where E is the earth's orbital velocity (18 miles per second), and e is the angle between the body's radiant and the point in the sky towards which the earth's orbital motion was directed at that instant. The angle e was determined by spherical trigonometry to be 129°; then the heliocentric velocity was 27 miles per second.

For a body moving on a parabolic orbit about the sun the velocity at the earth's distance is 26.2 miles per second. Considering the uncertainties of the solution, the excess of the computed velocity over this amount is not significant. We may therefore say that the velocity was parabolic or nearly so. It is probable that, previous to its encounter with the earth, the body was moving on an ellipse of high eccentricity.

Sounds

At distances up to about 20 miles from the projected path, sounds were heard following the sight of the fireball by variously estimated lengths of time and lasting for some time. The small letters on the map in figure 1 refer to the locations of the observers who heard the sounds. All of these except one were interviewed and asked to estimate the time interval between flash and sound as best they could. The results were as follows:

(a) Saw the light outside and at some unestimated time later heard (indoors) a loud sound, at first a series of bangings like horses kicking their stalls, but much louder, then a long-drawn-out "whoosh" like a chimney catching fire. The sounds lasted altogether for two minutes and seemed to come from the south.

(b) Twenty to thirty seconds after the light, heard many explosions like a stick of bombs falling, followed by "a sort of sound in the air".

(c) At the same time as the light (!), heard a noise like a rushing wind; the noise faded as the fireball passed from sight. (This observer was heard from by letter only. The writer believes these "sounds" coincident with the appearance of the fireball, were subjective only—a commonly noted effect.[3] Another observer at this same place failed to hear anything.)

(d) Twenty seconds after the light, sounds like thunder were heard indoors for three or four seconds. (The interviewer was convinced from the rapidity of this observer's re-enactment that he was underestimating the times.)

(e) Heard sounds like thunder some time after the light. The rumble started in the west and worked its way back towards the east.

(f) One to one-and-a-half minutes after the light, heard a rumble like heavy thunder to the west lasting for nine seconds. (This observer was emphatic about the time interval.)

(g) One minute and forty seconds after the light, heard sounds as loud as distant thunder; these came from a direction more west than north, lasted forty seconds and faded slowly. (This observer was definite about the times.)

(h) A rumbling beginning two minutes after the light and lasting 15 seconds.

(i) Two or three minutes after the flash, and lasting two or three minutes, there were very loud bangings like the bumping of an enormous tea kettle; these were first heard inside a car with a radio going; they rattled the windows and shook the ground; they appeared to come from the north.

(j) Two or three minutes after the light, heard a series of very loud sharp reports from the north and then a fading rumble, the whole sound lasted two minutes.

(k) Just over one minute after the light, heard a sound like fairly distant thunder which rumbled for 30 seconds and then changed to a whine like a siren which tapered off during a further 15 seconds; all sounds came from the north.

C. C. Wylie[3] has discussed the various sounds reported from meteors and has concluded that there are three kinds:

(*a*) A sharp detonation which he believes originates primarily from the shock-wave caused by a body moving faster than sound. This shock-wave travels at right angles to the direction of motion of the body and thus would appear to come from the closest point on the path. When the booms are repeated he believes they may arise from many small fragments after the bursting of the meteor. Echoes from buildings and hills and atmospheric irregularities, he believes, may contribute to the blurring of the sound or sounds into a roar which appears to retreat along the path in the direction from which the meteor was coming.

(*b*) A hum like an aircraft heard in the immediate vicinity of falls. He believes this is the actual whirr caused by the passage of the body after it has slowed down to less than the speed of sound.

(*c*) A swishing sound reported to be similtaneous with the sight of the meteor. He concludes that this is primarily due to suggestion and has no real existence.

As regards this present fireball, the sounds seem to fall, for the most part, in category (*a*), namely, those arising from one or more shock-waves. Most of the observers' accounts could be explained by a shock-wave followed by echoes and diffusions from atmospheric irregularities. Observer "e" voluntarily described the backing up of the sound along the path as though echoes were primarly responsible for the prolonged rumbling; other observers, however, did not mention this backing up, nor could they recall noticing it even when it was suggested to them.

Observers "a", "b", "j", and possibly "i" seemed to hear sharper sounds, less blurred and apparently all of about the same intensity. This suggests origin in several separate shock-waves rather than in echoes. However, it is to be recalled that no observers saw any bursting of the meteor during its illuminated path, as one might have expected if separate particles were to be involved in the shock-waves. It is perhaps significant that those who heard the separate detonations were located near the shore of the lake; the path of the sound over the water may account for less blurring by diffusion.

The time intervals between sight and sound as estimated by the observers are subject, one would expect, to considerable uncertainty. Nevertheless, they are not inconsistent with the distances of the points of observation from the computed earth-point: these distances range from 15 miles to 37 miles, and the corresponding range of time intervals, using 1100 feet per second for the speed of sound,

comes to 72 seconds to 3 minutes; most of the estimated intervals are within this range. The shock-waves heard by these observers must have originated at distances nearly equal to distances of the earth-point since the path was so steep.

One might be inclined to believe that the "whoosh" and the "whine" reported by observers "a" and "h" fall into Wylie's category (*b*)—sounds arising from the passage of the body in the lower atmosphere after the speed had been reduced to less than that of sound. The distances from the computed earth-point, however, seem rather large to be consistent with this view.

As inferred earlier, the "sounds" reported by observer "c" probably fall into Wylie's category (*c*)—subjective sounds. If this is the case, then two observers at this place (Lion's Head) failed to hear sounds, although less than 20 miles from the computed earth-point. The explanation may be as follows: in a three-dimensional model the plane through Lion's Head perpendicular to the meteor's path meets the path at an altitude of about a mile-and-a-half. If the last point of origin of the shock-wave were higher than this point then the shock-waves would miss Lion's Head and all points ahead of the intersection of this plane with the ground.

REFERENCES

1. R. A. McIntosh, *J.R.A.S.C.*, vol. 32, p. 18, 1938.
2. C. P. Oliver, *Meteors*, 1925 (Williams and Wilkins), Ch. xv.
3. C. C. Wylie, *Pop. Ast.*, vol. 40, p. 289, 1932.

Richmond Hill, Ontario
June, 1949.

NOTES AND QUERIES

Amateur Observatories in Canada

In a letter to the Editor Mr. E. K. White of the North Star Observatory, Chapman Camp, B.C., suggests the compilation of a catalogue of observatories owned by Canadian amateur astronomers and its publication in this Journal. This we cordially approve.

We ask every Canadian amateur who has an observatory to send in his name, address and a brief description of his observatory and its equipment, including type, focal length, etc., of telescopes and some account of any other apparatus.

An observatory would mean any permanent mounting for a telescope, from which the instrument might be removable for protection or the whole be sheltered by a lift-off cover, a roll-off roof or a dome of some sort. A simple portable telescope would not constitute an observatory.

Mr. White has expressed a willingness to undertake the formation of this list and every Canadian amateur is requested to send to him the information outlined above. Do it now!

C. A. C.

Nova in Scutum

Early in August announcement was made by the Astronomical "Clearing House" at Harvard College Observatory of the discovery by Ch. Bertaud at Meudon, France, of a nova in the constellation Scutum. This nova follows β Scuti by $8^m.7$ and is 35′ north of it. At discovery the magnitude was estimated at 9.6, by August 4 it had brightened to 8.5 and by August 30 its magnitude had faded to 9.9.

Spectrographic observations have been made at several observatories including the David Dunlap where we find this nova has the characteristic nova shell which is expanding at a rate of about 370 km./sec. This is a relatively slow velocity of expansion for a nova. In fact, in more ways than one, Nova Scuti appears to be behaving rather mildly and changing rather slowly.

J. F. H.

MEETINGS OF THE SOCIETY

AT EDMONTON

March 11, 1948.—The President called the meeting to order at 8:20 p.m.

The minutes of the previous meeting were read and approved.

The chairman announced that as the sky was clear, Dr. Campbell would take those who were interested to the Observatory at the conclusion of the meeting.

Mr. Burt gave an explanatory talk on latitude, longitude, altitude, azimuth, declination, and right ascension. These terms were illustrated with suitable diagrams and examples. The Handbook talk was given by Dr. Campbell.

The main paper on "A Trip to Mars" was given jointly by David Kinloch and Peter Crockford of University Intermediate School.

On the assumption that problems of space travel had been solved Peter Crockford took his audience on a trip to Mars, and discussed some of the things they might meet, and have happen to them. With the luck and endurance of Superman and Flash Gordon combined it was possible to deliver everyone safe home again.

David Kinloch then showed what part of such a trip is now possible, by telescope. He explained slides taken at Bloemfontein, South Africa. Photographs do not show the detail of Lowell's drawings, because the seeing is never perfect over the time of exposure.

The hope of getting better detail in movies taken by the extra light collected with the 200-inch telescope on Mount Palomar was mentioned by Dr. Campbell. Mr. Gibson brought greetings to the Edmonton Centre from Jean McDonald, and related having seen Mars and Saturn through the Victoria telescope recently.

The meeting adjourned for refreshments at 9:45 p.m. There were 34 members and visitors present.

April 8, 1948.—The President called the meeting to order at 8:21 p.m.

The minutes of the previous meeting were read and approved.

A report was given on the suggested examiners for the Boy Scout Association comprising people in Edmonton and in other Alberta towns. The Handbook talk was given by Dr. Campbell. Mr. Burt explained the following terms with the aid of diagrams: inferior and superior planets, transit, aberration of light, zenith and nadir.

The main paper was given by Mr. G. W. Paul on the subject "Radar and its Uses." All types of apparatus are based on one simple principle and upon eight or ten tricks of the trade. The main principle is of sending out very short radio pulses. These pulses are reflected from metal and other objects and when received show as a "blip" on the screen of a cathode ray oscilloscope. The oscilloscope has a time scale which is marked in distance by the use of the known velocity of the pulses so the range can be determined. Another type

known as a plan position indicator uses rotation of the sending antenna and a cathode ray screen with a long persisting visual image. This makes possible the showing on the screen of a rough map of the surrounding neighbourhood at the centre of which the observer's position is known to be. These principles and practices were well illustrated by a complete construction step by step in diagram form of one of the early sets made in Great Britain. In conclusion the speaker emphasized the many peace-time uses of radar in practice.

After some discussion the meeting adjourned at 10:00 p.m. for refreshments. There were 26 members and visitors present.

May 13, 1948.—The President called the meeting to order at 8:21 p.m. The minutes of the previous meeting were read and approved.

Mr. Deane explained the following terms with the aid of diagrams: eclipses—solar and lunar, stellar magnitude and parallax. The Handbook talk was given by Dr. Campbell. A new satellite to Uranus has been discovered of 17th magnitude.

The main paper was given by Rex Gibson on the subject "Lunar Mountaineering." Rex Gibson is proud of being one of these "crazy people" who climb mountains for fun. Once Everest is conquered then there must be "other worlds" to conquer. "The impossible is that which we have not yet learned to do." The moon's surface is better known than parts of Canada. A lunar club was proposed with Jules Verne as honorary innovator. Its object would be to explore the moon's mountains. The problems involved in this were summarised. Pictures from "Life" were projected to illustrate them. Photographs of the moon were shown, and some rock peaks in Colorado and New Mexico which are somewhat similar to those on the moon.

After some discussion and questions the meeting adjourned for refreshments at 10 p.m. There were 28 members and visitors present.

October 14, 1948.—The President called the meeting to order at 8:23 p.m. The minutes of the last meeting were read and approved.

Dr. Campbell gave the Handbook talk. Mention was made of the interesting features of the sky for the next month.

The main paper was given by Mr. Sheffield of the Mathematics Department on the subject of Comets. Comets, from quite ancient times, have attracted attention on account of the suddenness and unusualness of their appearance and movements. The most famous one is Halley's Comet which appears at intervals of about 75 years. Records indicate that it has been seen to return at about this interval for over 2000 years. A typical comet is believed to be a swarm of particles surrounded by gas, with mass very small compared to the earth's, going around the sun in a long elliptical path with the sun near one end. Hence it is generally visible only for a short time while near the sun. As it approaches, the sun's rays drive some of the gas away, forming the tail. Hence the tail usually follows the head during approach, but precedes it while going away.

After some discussion and questions the meeting adjourned for refreshments at 10 p.m. There were 37 members and visitors present.

November 18, 1948.—The minutes of the last meeting were adopted.

The Handbook talk was given by Dr. Campbell.

The main paper was given by Dr. E. H. Gowan, on the subject of "Electromagnetic Radiation." The main subdivisions of the electromagnetic spectrum are radio waves, infra-red (or heat) waves, light, ultra-violet, X-rays, and gamma-rays from radio-active substances. Explanations were given about the different experimental methods needed to discover and study the various types. In some cases these were illustrated with demonstration experiments. Finally a short account was given of the theoretical background of electromagnetic radiation. This gives unity and coherence to a great variety of behaviour over a very wide range of frequencies.

After some questions and discussion the meeting adjourned at 10 p.m. for refreshments. There were 38 members and visitors present.

December 16, 1948.—The dinner was held at 6:45 in the banquet room of the Corona Hotel. The meeting was called to order at 8:09 by the president, Dr. D. B. Scott. The minutes of the last meeting were read and approved.

The Handbook talk was given by Dr. Campbell.

The treasurer's report was read by Miss Smith, and having a satisfactory balance, was moved for adoption. The motion was seconded by Mrs. Clarke and carried. The secretary's report was moved by Dr. Gowan and seconded by Mr. Burt and carried. The Nomination Committee report was moved by Mr. Blower. There were no other nominations from the floor so the chairman declared the slate carried. The officers for 1949 are listed elsewhere in the JOURNAL.

A movie of solar prominences taken at McMath-Hulbert observatory was shown after an explanation by Mr. Phibbs. It showed features of solar prominences which cannot be seen by the naked eye even helped by a telescope.

The main address was given by Prof. S. Tweedie. There are many different ways of looking at stars but there is one particular educational aspect. Man has a soul which he insists on calling his own and to satisfy his curiosity he looks about him. Experiment in "spiritual star gazing" in Edinburgh was outlined as an example. It started with settlement work in slum areas organised by groups of students and faculty of the university. During the depression an exchange of skills was arranged in workshops. It was found that intellectual needs are important too and classes were organized to give study guidance in many fields of interest shown. This grew and made important contributions to slum clearance projects in the City of Edinburgh. A hearty round of applause was given Mr. Tweedie at the conclusion of his inspiring address.

Announcement was made that the January meeting would feature a showing of some of the Chant collection of slides. Comments and explanations of these slides would be by Mr. E. Phibbs, who is giving the astronomy course in the University this year. The meeting adjourned at 9:38 p.m. There were 42 members and visitors present.

E. H. GOWAN, *Honorary Secretary.*

AT OTTAWA

November 29, 1948.—The Annual meeting of the Ottawa Centre was at the Cafeteria of the Administration Building, Central Experimental Farm. There were about one hundred and forty members and friends present.

Dinner was served about 6.45 p.m. and after dinner an astronomical sing-song was led by Dr. Millman with Mr. Anhauser at the piano.

The business meeting followed, Mr. M. M. Thomson, the president, being in the chair. It was moved by Mr. Lloyd and seconded by Mr. Matley that the minutes of the last annual meeting be taken as read. Carried. The secretary's report was read and adopted on a motion of Miss Hicks seconded by Mr. Matley. The treasurer's report was presented by Mr. Mott, who moved its adoption, seconded by Mr. Henderson. Carried. The scrutineers, Miss Stacey and Mr. Cross, appointed by Mr. Thomson immediately following dinner, then gave their report. Twenty-five ballots were received, all good. Officers for 1949 are listed elsewhere.

Mr. Thomson then extended thanks to the members of Executive and Council for their efforts during the year; to the Press, Museum, Public Libraries, Y.M.C.A., Y.W.C.A., and all others who had helped publicize the lectures; to the speakers and the members for their presence; to Dr. Archibald for use of the cafeteria; and to Miss MacMillan and her staff for the preparation of the dinner.

Mr. Thomson then introduced Dr. Beals, the speaker of the evening. Dr. Beals gave a most interesting account of his impressions during his trip to Europe last summer when he attended the meetings of the International Astronomical Union and the International Geophysical Union. He was thanked by Mr. Matley.

Dr. Millman thanked Mr. Thomson for his work during the past two years and the meeting adjourned.

AT TORONTO

February 12, 1949.—Joint meeting with the Royal Canadian Institute, held in Convocation Hall.

Dr. Ralph E. Williamson, Assistant Professor of Astronomy, University of Toronto, gave an address on the subject: "Radio Waves from Sun and Stars."

The speaker pointed out that mankind's knowledge of the Universe has increased with the development of instruments which have augmented his sense of vision and have allowed him to record photographically those features which otherwise could not be seen. Galileo's discoveries, in 1610, precipitated a complete change of thought regarding the Universe, and later the photographic plate and the spectrograph provided means of analysing the light from the stars, thus presenting a new angle for study. The recent discovery that radio waves are emitted with perceptible intensity from celestial bodies, and the development of the "radio telescope", may further broaden the astronomer's field of investigation.

In 1931, Karl G. Jansky, a young radio engineer of the Bell Telephone

Laboratories at Holmdel, New Jersey, while making measurements of short-wave radio static, discovered that the source of a peculiar steady, hissing type of static, which varied slowly in its direction throughout the day, came from a fixed direction in space known as the centre of the galaxy.

This discovery prompted the development of the radio telescope, a new tool for exploring the Universe. Radio waves and light waves, electromagnetic vibrations with entirely different wave-lengths, provide astronomers with quite different information about their astronomical sources. The radio telescope, essentially a very sensitive radio receiver, has large antennae which can be directed toward any astronomical object, and a meter registers the strength of the waves after amplification. The techniques of using these telescopes are not yet developed

At present, observations by the new instrument indicate that many astronomical objects exist which emit radio waves and yet give no evidence of their presence by light waves. More than half a dozen sources of radio radiation have been discovered which give no evidence of any connection with other well-known astronomical objects, whether stars, star clusters, bright or dark nebulae, or external galaxies. What these "celestial radio stations", which broadcast incessant static, might be is an exciting puzzle for the astrophysicist. In the immediate future, radio and optical observations together may find whether our galaxy has the same spiral structure as most other galaxies. The mass of stars and interstellar gas and dust prevent observation through the Milky Way by optical telescopes.

Radio telescopes may become of great value in studying sun-spots and their emission of radio waves which affect the earth's magnetic field and consequently disturb broadcasting. The astrophysicist is always in search for new methods of investigating the sun as a source of radiations and their influence upon the electrical and optical properties of the upper atmosphere. Study of this radiation with the radio telescope may help to solve the problems of the structure and cause of sun-spots.

February 22, 1949.—The meeting was opened at 8 p.m. in Room 101, McLennan Laboratory, Mr. A. R. Clute, President, in the Chair.

Minutes of the previous meeting of February 12 were taken as read.

Upon motion by the Secretary, seconded by Mr. Dale, By-Law No. 1 of the Constitution was suspended and ten new applicants for membership, now being nominated, were elected at this meeting, as follows:

Mr. Stanley Armour, 48 Lawton Blvd., Toronto 12.
Mrs. Anne Olive Bacon, 309 Briar Hill Ave., Toronto 12.
Mr. Kenneth Cashmore, 11 Marigold Cres., Clarkson, Ont.
Mrs. L. C. Ecker, 711 Oriole Parkway, Toronto 12.
Mr. Frederick Fleet, Box 76, Glen Williams, Ont.
Mr. Garfield W. Gunstone, 79 Swanwick Ave., Toronto 13.
Mr. Hilbert J. Hartman, 213 Keewatin Ave., Toronto 12.
Mr. Donald B. Lockwood, 386 Parliament St., Toronto 12.
Mr. Malcolm B. Lennox, 24 Dundurn Cres., Toronto 10.
Mr. Elmer Mulvenna, Mount Pleasant, Ont.

The Chairman called upon Mr. R. W. Tanner to initiate and lead a discussion on "Time—How we find it and how to use it."

The speaker showed two moving picture films:

1. Entitled "Time"—through the courtesy of the Elgin Watch Company. This film illustrated the early shadow type and water clocks, and showed the developments through the years to the latest designs of watches and in precise methods of checking time, with some suggestions of the importance of a reliable timepiece in our modern method of living.

2. "Celestial Navigation—The Earth"—through the courtesy of the U.S. Navy. This film explained the meaning and use of latitude and longitude and the method of charting courses for navigators.

Following these films there was a brief discussion, chiefly in regard to positions of fixed stars and the difference between solar and sidereal time.

The Chairman expressed the thanks of the meeting to the speaker for his assistance, and then read a description of a method of telling time by the stars, using Beta Cassiopeia and Polaris.

The Chairman drew attention to the exhibit of navigation instruments in Room No. 305. Many members were interested in examining these instruments and inquired as to their manipulation and applications.

March 8, 1949.—The Chairman, Mr. A. R. Clute, announced that on March 22 there would be a Members night on the subject of telescopes described and displayed by the Telescope Maker's Group. He announced a public meeting to be held on April 5 at which Dr. Donald MacRae from the Warner and Swasey Observatory, Cleveland, will speak on the "Milky Way". The Chairman further drew attention to a meeting of March 25 of the Canadian Rocket Society at which Dr. J. F. Heard of our Society will speak on "Conditions existing in Planets as we know them today."

Dr. R. E. Williamson introduced the speaker, Dr. C. W. Gartlein, Department of Physics, Cornell University, to speak on the subject "Recent Studies of the Aurora Borealis."

Dr. Gartlein in his opening remarks mentioned that his studies of the Aurora were commenced about 11 years ago and emphasized that Toronto was particularly well located to view the Northern Lights. He then showed a series of spectacular slides of aurora formations, classifying them in two groups, the arc and drapery types, *i.e.*, the corona borealis and aurora borealis, and pointed out the interesting characteristics of each type. The arc formations run from east to west, with the west edge higher than the east edge, and in the drapery type all rays are essentially parallel.

By graphs, the speaker showed that the peaks of aurora displays occur in April and September, and that there are 12-15 auroras per year. There appears to be some relationship, though rather poor, between the number of auroras per year and the sun-spot activity. The graphs show that the peaks of frequency of aurora displays are slightly later than the peaks of sun-spot activity. The chances are that auroras will appear on two successive nights and then a lapse of 27 days will occur until the next display, this lapse being practically equal to the period of rotation of the sun.

Aurora displays occur about 200 miles above the earth's surface and are caused by the radiation of electrically charged particles from sun-spots which disturb the earth's magnetic field. These displays occur only during major magnetic disturbances, not otherwise. The rays show the direction of the lines of force of the earth's field.

While designated as "Northern Lights" some illuminated areas may be seen to the south of the zenith, and may be confused with clouds, but can be distinguished by the fact that auroras are transparent so stars may be seen through them more clearly than even through thin clouds.

The northern hemisphere is the most favoured part of the earth for aurora observation and the greatest number of displays per year may be seen from the Toronto area.

The speaker showed, by slides, a variety of instruments used in making observations and measurements, followed by some coloured slides and spectra of aurora, and drew attention to the relation shown between aurora and magnetic disturbances which are felt in serious interruption of communication services on the earth.

A short discussion followed, the inquiries being chiefly whether other planets have aurora displays and whether there actually are any sound effects from our Northern Lights.

The speaker explained that aurora displays require an atmosphere and a magnetic field. Observation of such displays would indicate that the planet is magnetized, an interesting item of information, but observers probably could not distinguish an aurora due to the light reflected from the planet. Auroras are not restricted to the presence of oxygen in the planet's atmosphere.

As to the existence of sound effects, the speaker stated that he had never heard sound which definitely could be attributed to the aurora, and that such weak sounds, if existing, could not be amplified due to the level of background noises in detector and amplifier tubes. For this reason, the ear is more sensitive to very weak sound waves than the microphone and amplifier.

In proposing a vote of thanks to the speaker, Dr. Helen S. Hogg mentioned several interesting viewpoints held in different countries regarding the Northern Lights.

Mr. Clute read a poem on the Aurora by Albert Durant Watson, a former member of the Toronto Centre.

F. K. DALTON, *Recorder*

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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA
1890-1949

The Society was incorporated in 1890 under the name of The Astronomical and Physical Society of Toronto, and assumed its present name in 1903.

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal and Quebec, P.Q.; Ottawa, Toronto, Hamilton, London, and Windsor, Ontario; Winnipeg, Man.; Saskatoon, Sask.; Edmonton, Alta.; Vancouver and Victoria, B.C. As well as nearly 1500 members of these Canadian Centres, there are over 400 members not attached to any Centre, mostly resident in other nations, while some 160 additional institutions or persons subscribe to our publications.

The Society publishes a bi-monthly "Journal" containing about 350 pages and a yearly "Observer's Handbook" of 80 pages. Single copies of the "Journal" are 50 cents, and of the "Handbook," 40 cents.

Membership is open to anyone interested in astronomy. Annual dues, $3.00; life membership, $40.00. Publications are sent free to all members or may be subscribed for separately. Applications for membership or publications may be made to the General Secretary, 3 Willcocks St., Toronto.

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